Introduction

Why Study It?

The processes comprising the global environment are interconnected. Many of the major environmental issues of our time have driven scientists to study how these connections operate on a global basis – to understand the Earth as a system.

Studies of the stratospheric ozone layer involve questions about the processes which create and destroy ozone. Different chemicals, present in the air in trace amounts, control the abundance of ozone in the atmosphere. The sources of these trace constituents include microorganisms in the soil and water, land plants, and even some animals. Scientists have learned that ozone, a chemical primarily found in a layer centered about 25 km above Earth's surface, is connected to biological activity happening below Earth's surface.

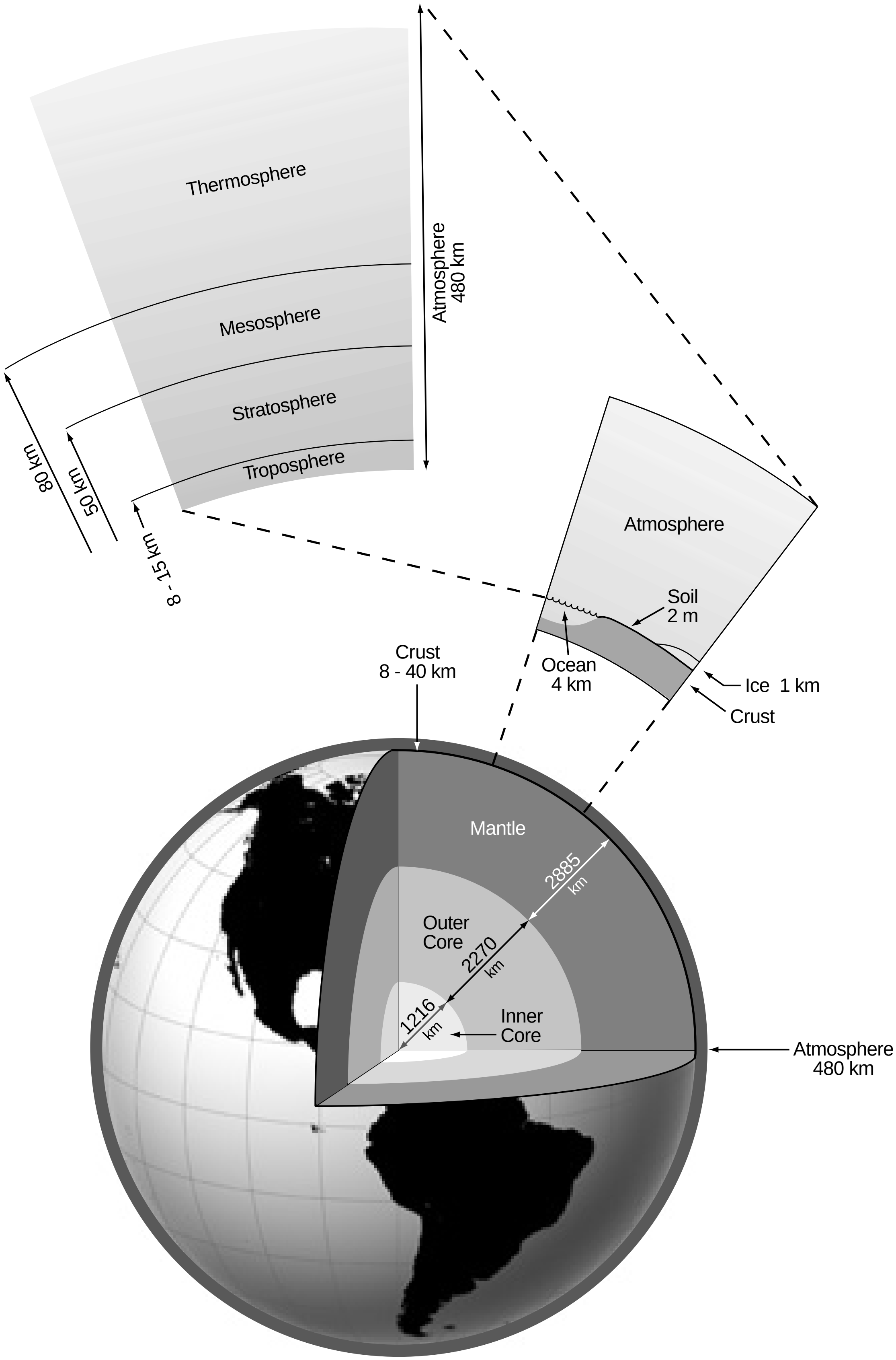
Studies of climate change have also forced scientists to look at connections. Some of the trace gases in the atmosphere make it more difficult for heat (infrared light) to escape from the Earth's surface to space. The amounts of these greenhouse gases found in the atmosphere are tied to the physical, chemical, and biological processes taking place in soil and water and on land. They are also influenced by the circulation of the oceans and atmosphere. To predict the future course of the climate we need to understand this detailed fabric of connections.

Ecologists always look for the significant components of the ecosystem they are studying. The living and non-living components of an ecosystem interact. Individual organisms and species compete and cooperate with one another. In some cases, interdependence is so strong that different plants and animals cannot reproduce or even exist without each other. There is a web of life with extensive recycling of nutrients, and each organism plays a role. If one component of the ecosystem is changed the effects ripple through the system.

Scientists do not know all the Earth system connections yet, but they keep working to gain a more complete understanding. GLOBE students can help through their data-taking and student research. GLOBE students and scientists working together will improve our understanding of the Earth system. As students conduct the full range of GLOBE measurements (perhaps spread over several school years in multiple grades), they should gain a perception that the environment is the result of an interplay among many processes that take place locally, regionally, and globally on time scales ranging from seconds to centuries. This is a key GLOBE lesson. The learning activities in this chapter help students learn this by studying annual variations in environmental parameters (the Seasons and Phenology section) and by examining the connections among the various phenomena measured in GLOBE on local, regional, and global spatial scales (the Exploring the Connections section).

In addition to learning activities, there are phenology protocols within the Seasons and Phenology section. Phenology is the study of living organisms' response to seasonal changes in their environment. Change in the period between green-up and senescence, often synonymous with the growing season, may be an indication of global climate change. Broad-area estimates of the lengths of growing seasons are primarily based on satellite data. However, remote sensing estimates from satellites are not exact because the actual behavior of the plants must be inferred from the aggregate appearance of their foliage. GLOBE student observations, the only global network of ground-based plant phenology observations, will help scientists validate their estimates of global greenness values that they derive using satellite data. Monitoring the length of the growing season is important for society so that it can be better prepared to adapt not only to variations in the length of the growing season but also to other impacts of climate change which may affect food production, economic growth, and human health.

Figure EA-I-1: Schematic Diagram of the Earth System from the Center of the Earth to 480 km up into the Atmosphere



The Big Picture

Perceiving Earth as a system begins when we first feel warmth from sunshine or get wet standing in the rain. Understanding Earth as a system – Earth System Science – requires a quantitative exploration of the connections among all parts of the system. The measurements of the GLOBE Program provide students with the means to begin this exploration for themselves.

The parts of Earth are the core, mantle, crust, soil layers, oceans and inland water bodies, ice, and atmosphere. See Figure EA-I-1. The processes studied in physics, chemistry, and biology connect them all. Earth system science focuses on the processes which take place in the atmosphere, oceans, fresh water bodies, ice (cryosphere), soils (pedosphere), vegetation growing on the land surface which connects the soil and atmosphere, plus the energy from the sun which drives these processes, and the gases and particles which enter the atmosphere and oceans from space or from the layers of molten and solid rock beneath Earth's surface (lithosphere). Many of these processes involve life, so scientists also speak of the biosphere – the combined places on Earth where organisms live.

Instead of focusing on the different parts of Earth, the study of Earth as a system focuses on cycles that connect these parts. These are the cycles of energy, of water, and of the individual chemical elements (e.g., carbon). In each cycle there are places where energy, water, or individual chemical elements are stored for a period of time (reservoirs) and different forms in which they are stored (e.g., chemical energy, sea ice, or carbon dioxide). Also, there are processes which change the form of the energy, water, or chemical elements (e.g., photosynthesis, condensation, or fire) or move them from place to place (fluxes: e.g., precipitation, transpiration, ocean currents, wind, river flow). Earth system scientists want to know the sizes of the reservoirs and fluxes and to understand the processes that control them. Every GLOBE measurement is designed to support the determination of these reservoirs and fluxes.

Energy from the sun flows through the environment, warming the atmosphere, the oceans, and the land surface, and fueling most of the biosphere. See Figure EA-I-2. Differences in the amount of energy absorbed in different places set the atmosphere and oceans in motion and help determine their overall structure. These motions redistribute energy throughout the environment. Eventually the energy which began as sunshine leaves the planet as Earth shine (light reflected by the atmosphere and surface back into space) and infrared radiation (heat) emitted by all parts of the planet which reaches the top of the atmosphere. This flow of energy from the sun, through the environment, and back into space is a major connection in the Earth system; it defines Earth's climate.

Water and chemical elements are cycled through the environment. Water melts, evaporates, condenses, and freezes, and is moved from place to place in the atmosphere, the oceans, across the land surface, and through soil and rocks. See Figure EA-I-3. Each of the chemical elements undergoes chemical reactions, but the total amount of each on Earth remains fixed except for the transformations associated with nuclear energy and radioactivity and the loss of a small amount of hydrogen from the upper atmosphere to space. In this way, the environment consists of a set of cycles for water, carbon, nitrogen, phosphorous, etc. Scientists speak of these as the hydrologic (water) cycle, the carbon cycle, the nitrogen cycle, and so on. Since the cycles of the elements involve life and happen on Earth, they are collectively known as biogeochemical cycles. Figure EA-I-4 shows one of these, the carbon cycle.

Figure EA-I-2: Schematic Diagram of the Earth's Energy Budget

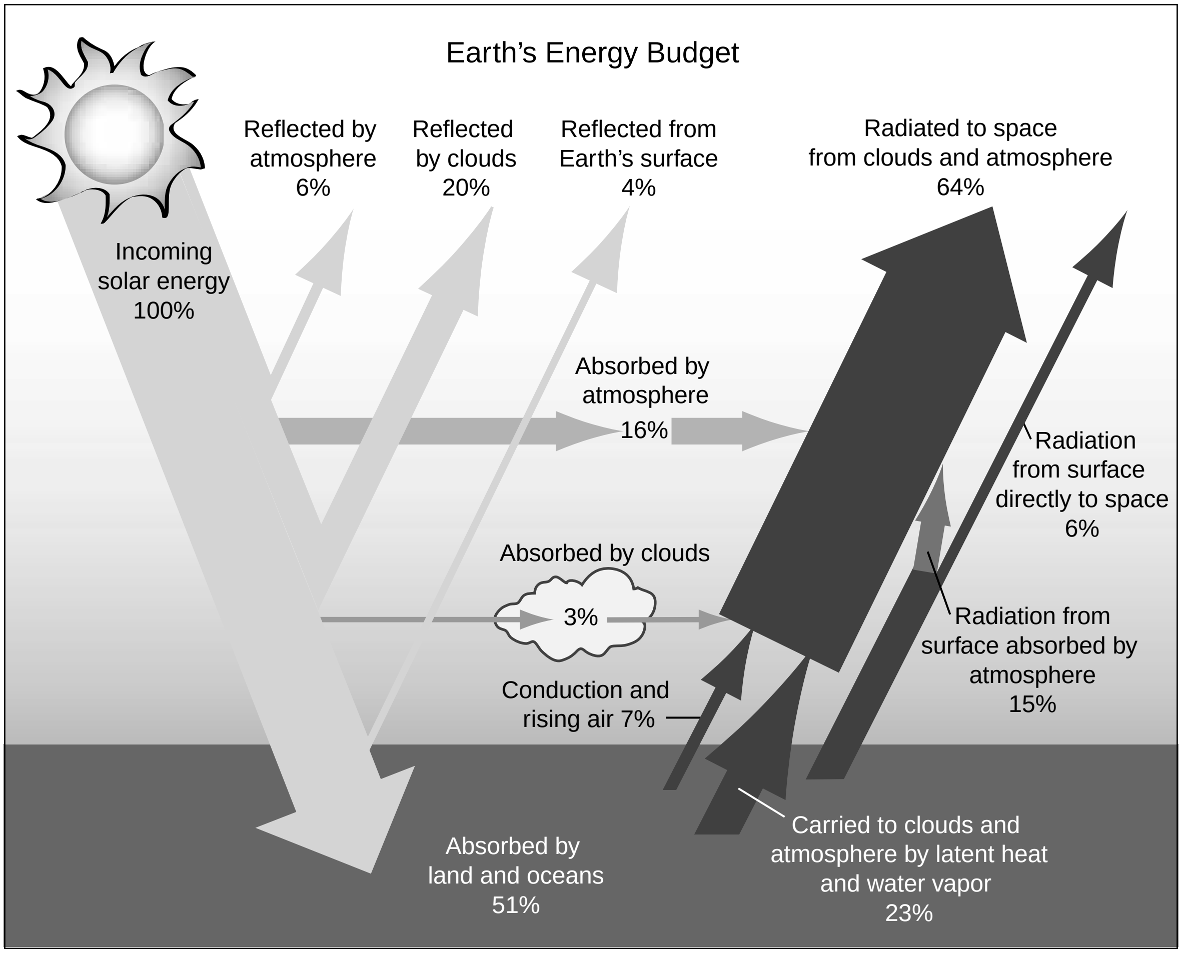


Figure EA-I-3: The Hydrologic Cycle

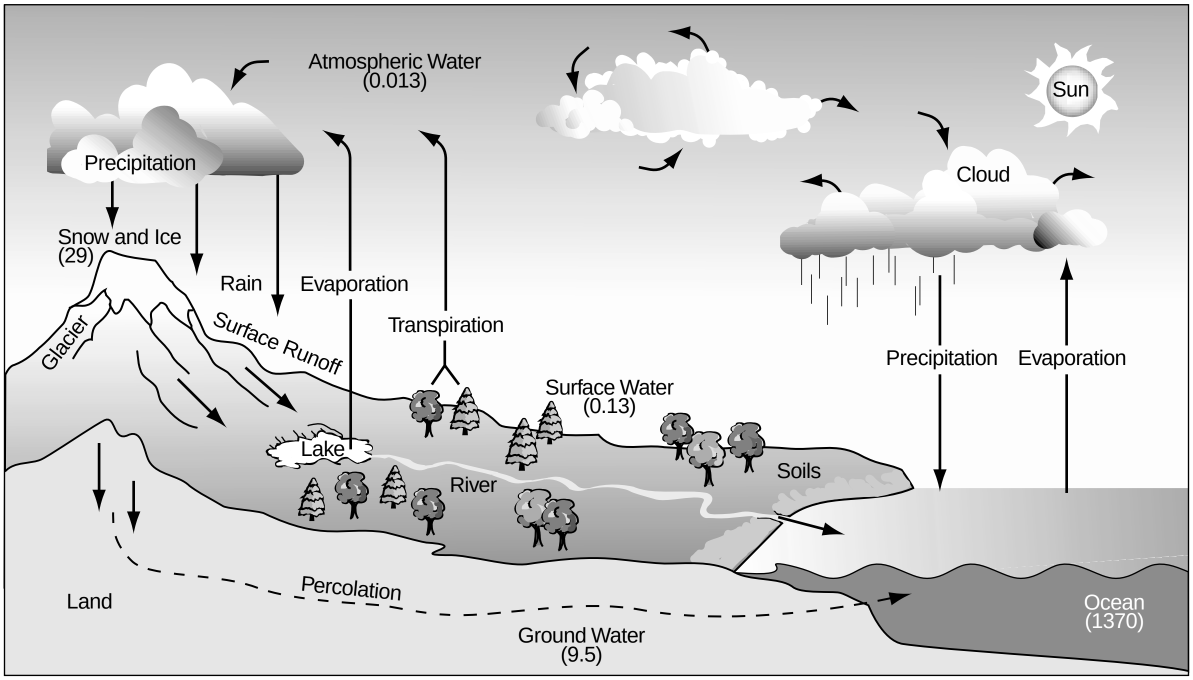
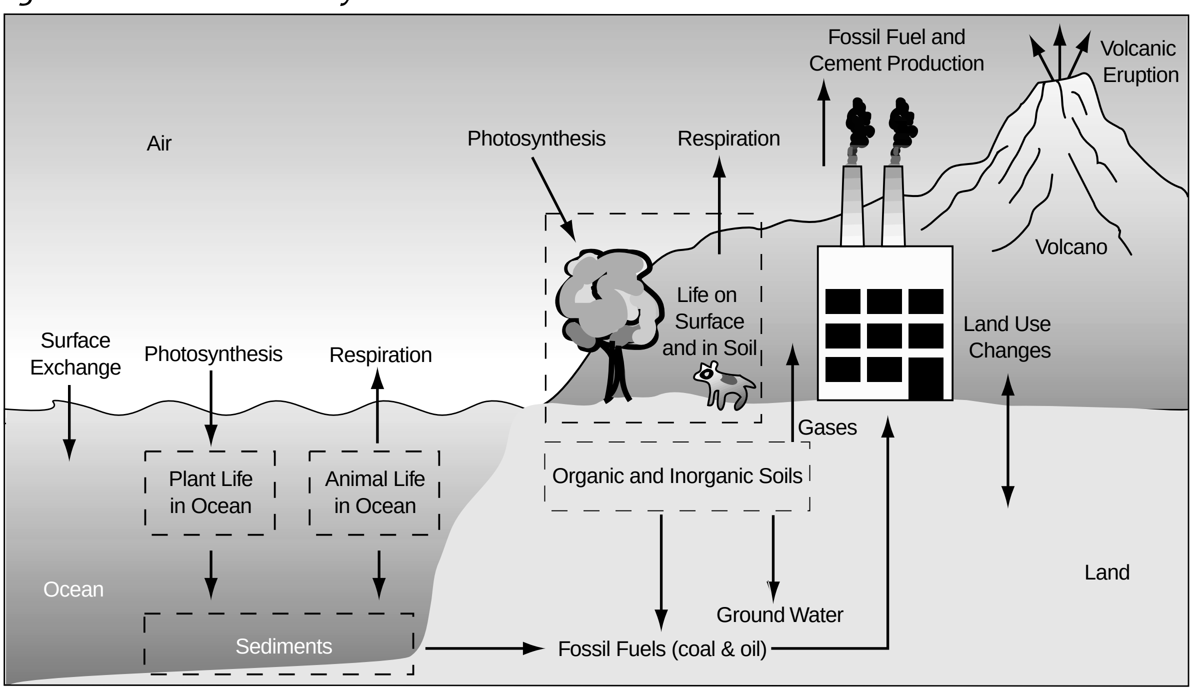


Figure EA-I-4: The Carbon Cycle



Components of the Earth System

The GLOBE program has students take measurements of parts of the Earth system. The table below indicates where the GLOBE investigations lie with the components of the Earth system.

Components of the Earth System	GLOBE Investigations
Atmosphere (Air)	Atmosphere Investigation
Oceans and Fresh water bodies	Hydrology Investigation
Cryosphere (ice)	Atmosphere Investigation (solid precipitation) Hydrology Investigation (frozen water sites)
Soil	Soil Investigation
Terrestrial (land) vegetation	Land Cover Investigation Earth as a System Phenology Investigation

Cycles of the Earth System

In the environment, energy can be in the form of radiation (solar or short-wave radiation and infrared or long-wave radiation), sensible heat (thermal energy), latent heat (heat released when water goes from the gas to the liquid or solid state), kinetic energy (energy of motion including winds, tides, and ocean currents), potential energy (stored energy), and chemical energy (energy absorbed or released during chemical reactions). Scientists want to know, model and predict the amount of energy in each component of the Earth system, how it is exchanged among the components, and how it is moved from place to place within each of the components. The energy cycle is intertwined with the hydrologic cycle. Some of the energy in the sunlight reaching Earth's surface causes evaporation from surface water and soils. The atmosphere transports the resulting water vapor until it condenses in clouds, releasing the energy that evaporated the water. Water droplets and ice particles in clouds grow in size until they form precipitation, falling to the surface as rain, snow, sleet, or hail. Once the precipitation falls, the water can remain frozen on the surface to melt at a later time, evaporate again into the atmosphere, fill spaces in the soil, be taken up by plants, be consumed by animals, leach through the soil into groundwater, run off the land surface into rivers, streams, lakes and ultimately into the oceans or become part of a surface water body. Snow and ice reflect more sunlight back to space than ocean water or most other types of land cover, so the amount of snow or ice covering Earth's surface affects the energy cycle.

Together, the combined energy and hydrologic cycles affect the biogeochemical cycles. In the atmosphere, chemical reactions driven by sunlight create and destroy a rich mixture of chemicals including ozone. Some of these chemicals combine with water to form aerosols –liquid and solid particles suspended in the air. Atmospheric chemicals and aerosols become incorporated in water droplets and ice crystals and are carried from the atmosphere to the surface by precipitation. Microorganisms in the soil and surface waters, plants, and animals all take in chemicals from the air and water around them and release other chemicals into the atmosphere, fresh water bodies, and oceans. Winds pull water drops and soil particles from the surface and they become aerosols. Agricultural and industrial activities also input and remove energy, water, gases, and particles from surface waters, soil, rocks, and air. The quantity and distribution of gases such as water vapor, carbon dioxide, nitrous oxide (N_2O), and methane in the atmosphere determine how infrared radiation is absorbed and transmitted between Earth's surface and space. This in turn affects the temperature at the surface and throughout the atmosphere. There are many other ways in which the energy, water, and biogeochemical cycles interact and influence our environment, far more than can be described here.

How GLOBE Measurements Contribute to Earth System Studies

GLOBE measurements of the temperature of air, water bodies, and soil help track the energy cycle. GLOBE students also measure cloud cover, cloud type, atmospheric haze, water transparency, and land cover. Each of these observations helps scientists determine what happens to sunlight and thermal infrared radiation (heat). How much sunlight is reflected or absorbed by clouds or Earth's surface? How much out-going infrared radiation is absorbed or reflected back downward?

GLOBE measurements of liquid and solid precipitation, relative humidity, soil moisture, land cover, and canopy and ground cover and the identification of the dominant and codominant species of trees help track the hydrologic cycle. Knowing the profile of the top meter of soil and its infiltration characteristics enables scientists to calculate how water will pass into and through the soil; soil bulk density and particle density determine how much water can be stored in the soil. Measurements of the surface temperature of a water body and of soil moisture and temperature enable estimation of evaporation rates. How much rain falls on Earth? Is the hydrologic cycle becoming more intense; in other words, are the various fluxes in the cycle increasing?

GLOBE observations contribute to the study of the biogeochemical cycles. Measurements of the pH of precipitation, soil horizons, and surface waters are fundamental because the pH influences how the different chemical elements interact with the water flowing through the environment. Lowering pH can mobilize different chemicals from the surfaces of rocks and soil particles. Living plants are a significant reservoir in the carbon cycle. Measurements of the mass of dried grasses and the circumference and height of trees enable estimation of how much carbon is stored in the living biomass of a forest or grassland. As carbon is added to the atmosphere, how much is taken out by terrestrial vegetation?

Open versus Closed Systems

If you look at Earth from outer space, the Earth is an almost *closed system*. A closed system is one in which no matter enters or leaves. (An isolated system is one in which no matter or energy enters or leaves.) Other than the transfer some gases and particles entering Earth's atmosphere, the components remain on Earth without new additions. When studying Earth as a whole, you usually do not need to consider the effects of inputs and outputs to the Earth system except for sunlight.

Smaller systems can be nested within larger systems. For instance, you can study a watershed — the land area which all drains into a common water body. Watersheds come in a variety of scales with smaller ones combining to form larger ones. For example, you could study all the area which drains into the Arctic Ocean or focus on the MacKenzie River basin in Canada or on just the Liard River which is a tributary of the MacKenzie and so on. Where you define the boundaries of your system, as a watershed, depends on the questions being asked. These concepts will be developed more in *Exploring the Connections*.

Any system within the Earth system, such as a watershed, is considered an *open syste*m. Water and chemicals as well as energy enter and leave the boundaries of the system. Still the components of this open system may be more closely connected to one another than they are to exchanges between the system and its surrounding, but the inputs and outputs may be important for understanding the dynamics of the system you are studying.

Scales of Space and Time

All the processes of the Earth system occur on specific space and time scales. Some occur on a scale so small that our eyes cannot see them, while other phenomena cover an entire continent or happen globally. The time scales for different phenomena vary tremendously as well. Some atmospheric chemical reactions happen in fractions of a second. The formation of soil with its interplay of physical, chemical, and biological characteristics happens locally over many years (generally at a rate of 1 cm of depth per century). Major weather systems including hurricanes usually develop and dissipate on time scales of one to two weeks and cover hundreds of kilometers.

Parts of the various cycles of the Earth system can be measured and understood locally on relatively short time scales, seconds to days; in other cases, one must try to characterize the whole globe for decades to test theories, understand processes, and gain overall knowledge. Let's consider one example of each situation:

1. **The balance in the amount and flow of water in a small watershed.**
   One can sample the input of water by measuring precipitation at one or more sites (the more sites, the better the estimate can be). The evaporation of water can be calculated from temperature measurements of the surface soil and water and knowledge of the surface soil moisture and particle size distribution or texture. The transpiration of water by trees and other plants can be estimated by mapping the land cover, measuring canopy and ground cover at a number of sites, and identifying the dominant species of trees in the forests and woodlands. Measurements of soil moisture and the levels of streams, lakes, and rivers tell how much water is stored in the watershed (discounting aquifers or other major underground water bodies). The level of the stream or river through which water flows out of the watershed is an indication of how fast this flow is. If one understands the local situation and measures it adequately, the inputs and outputs must balance with the change in the amount of water stored. Most of the needed measurements are included in the GLOBE protocols and the others can often be obtained from other sources or measured with help from local scientists.
2. **Understanding the El Niño/Southern Oscillation (ENSO)**
   The warm episodes of the ENSO occur at irregular intervals of two to seven years. Changes develop across the entire equatorial Pacific basin and effects have been observed to develop as much as six months later throughout the temperate zones of both hemispheres. Small remnant phenomena from warm events have been observed by satellites as much as ten years later. To thoroughly characterize this phenomenon and its effects one must take data for many years on almost a global basis and carefully look for connections, causes, and consequences. Predictions based on an overall understanding of the ENSO can be examined locally using data records covering many months including the data sets collected and reported as part of GLOBE. GLOBE student data of air temperature and precipitation can be compared with model predictions of ENSO effects to help determine the adequacy of our current understanding and modeling abilities.

Key Concepts

As discussed in the previous pages, when studying Earth as a system, there are a few key concepts to understand. These are:

- The Earth is a system made up of components.
- The components interact through specific processes.
- Phenomena happen on a range of time and spatial scales.
- Connections among phenomena can be traced through the energy, hydrologic and biogeochemical cycles.
- Energy, water, and the chemical elements are stored in various places and forms and are transported and transformed by various phenomena and processes.

The Earth as a System

The Seasonal Cycle

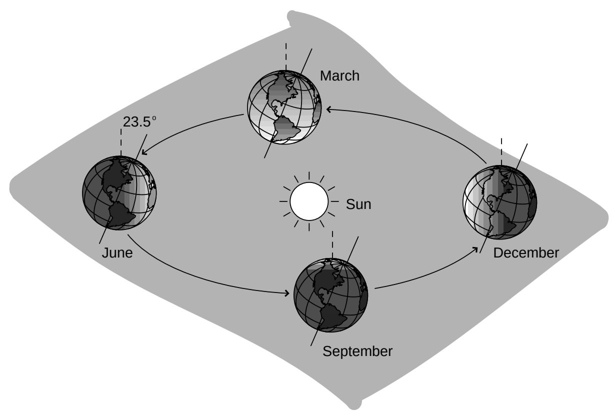
The Seasonal Picture: Why are there seasons?

Like tides washing regularly across a beach, seasons advance and retreat across the face of the globe and bring a rhythm to our lives. Whether it is the arrival of winter snows, monsoon rains, or summer heat, our environment changes constantly, and these profound changes occur over relatively short time periods. What helps make such huge, complex changes comprehensible is that they recur in predictable ways. Many ancient civilizations observed that the Sun's position in the sky changed throughout the year and were able to construct calendars and make predictions based on their observations.

All seasonal changes are driven by shifts in the intensity of sunlight reaching Earth's surface (i.e., the amount of insolation). For example, more energy leads to higher temperatures which results in more evaporation which produces more rain which starts plants growing. This sequence describes Spring for many mid-latitude climates. Since visible light is the main form of solar energy reaching Earth, day length is a reasonably accurate way to gauge the level of insolation and has long been used as a way to understand when one season stops and the next one starts. For example, the first day of summer, the summer solstice, is the longest day of the year. Winter starts on the shortest day of the year, the winter solstice. The first days of spring and fall are when the day and night are of equal length - roughly 12 hours each. These days are named the vernal and autumnal equinoxes.

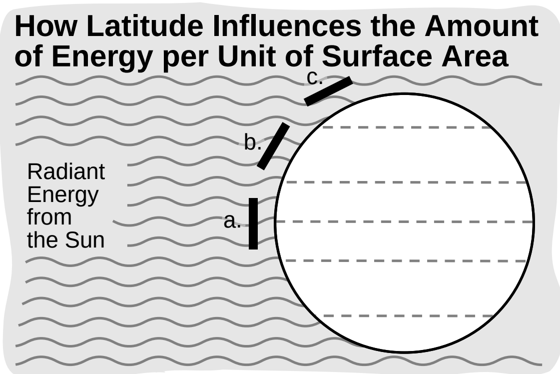
Changing day length implies that Earth's axis of rotation is inclined with respect to the plane of its orbit around the sun. The ancient Greeks knew that it was inclined 23.5˚. Figure EA-I-5 shows the inclined Earth at different positions in its orbit. Notice how at the solstice positions, each pole is tilted either toward or away from the Sun. The pole inclined toward the Sun receives 24 hours of sunlight, and the one inclined away is in Earth's shadow and experiences 24 hours of darkness. At the equinox positions, Earth is inclined in a way so that each pole receives equal amounts of insolation. This discussion focuses on the poles because they experience the greatest extremes of insolation. Because of the inclination of Earth's axis, insolation levels at every point on Earth change constantly. We call the aggregate effects of these changing levels seasons.

Figure EA-I-5: Tilt of the Earth's axis



The tilt in Earth's axis of rotation has an additional effect which amplifies the length of day effect. At every latitude, the Earth's surface is at a different angle with respect to the incoming sunlight. Look at Figure EA-I-6. When the surface is perpendicular to the sunlight, the sun is straight overhead, and the amount of sunlight striking a fixed area is at its maximum. As this angle between the surface and the sunlight changes and the sun is lower in the sky, the amount of sunlight striking the same area gets smaller. In the summer, the sun is closer to being straight overhead at local solar noon than in the winter except close to the equator. So, not only is the day longer in summer than in winter, but the sun delivers more energy to each unit of area of Earth's surface in the hemisphere where it is summer.

Figure EA-I-6: How Latitude Affects the Amount of Incoming Energy from the Sun

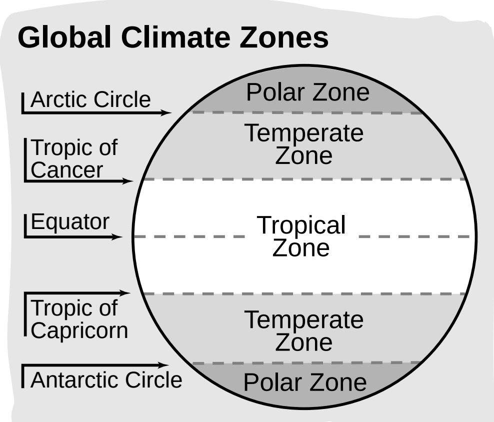


Factors Influencing Local Seasonal Patterns

Latitude

Figure EA-I-7 shows how insolation levels vary with latitude throughout the year. Because of this variation, latitude has a powerful influence in determining seasonal conditions and the annual patterns of environmental and climatic parameters such as precipitation and temperature. Because of the differences in the duration and directness of insolation, the world can be divided into zones shown in Figure EA-I-8. The same season can be quite different in the Tropical, Temperate and Polar zones.

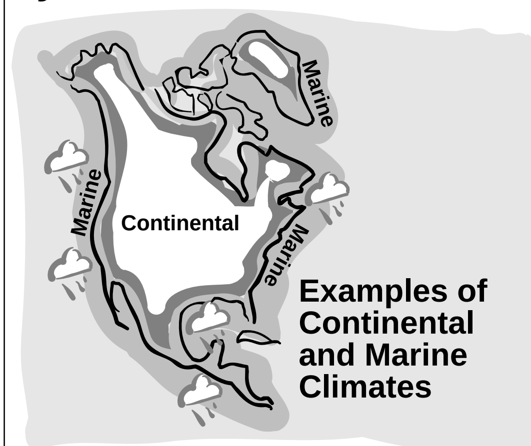
Figure EA-I-8: Global Climate Zones



Continental and Marine Climates

When sunlight strikes surface water, two things happen that keep the water surface from warming as much as the land surface. First, some of the sunlight penetrates many meters into the water column. This spreads the incoming energy down into the water body and the surface is less warmed. Also, colder water from lower depths mixes to some extent with the surface water and moderates its temperature changes. Second, and more importantly, as surface water warms, evaporation increases. Evaporation cools the surface and so the temperature of the water surface responds less to solar heating than the land surface. Land which is near large bodies of water that do not freeze in winter has a marine climate. This features larger amounts of moisture and smaller temperature changes from summer to winter than a continental climate. The size of a continent affects both the temperature range and the amount of moisture in the interior – the larger the continent, the further away the ocean and the larger the difference between summer and winter. See Figure EA-I-9.

Figure EA-I-9: Continental and Marine Climates



Wind Direction

The direction of the prevailing winds also affects local climate. If an area is downwind of the ocean (the west coasts of continents in mid-latitudes) the climate is strongly affected by the presence of the ocean in the way described above. If the winds are blowing from the interior of the continent, then they tend to be dry and to bring with them the larger contrasts in summer and winter temperatures. Areas in the high latitude parts of the temperate zones and downwind of unfrozen lakes receive large amounts of lake-effect snow while the lakes are unfrozen. Generally, prevailing winds connect the local climate with that upwind. Seasonal changes in prevailing wind direction can make seasonal contrasts greater or smaller.

Figure EA-I-7: Incoming Solar Radiation Throughout the Year

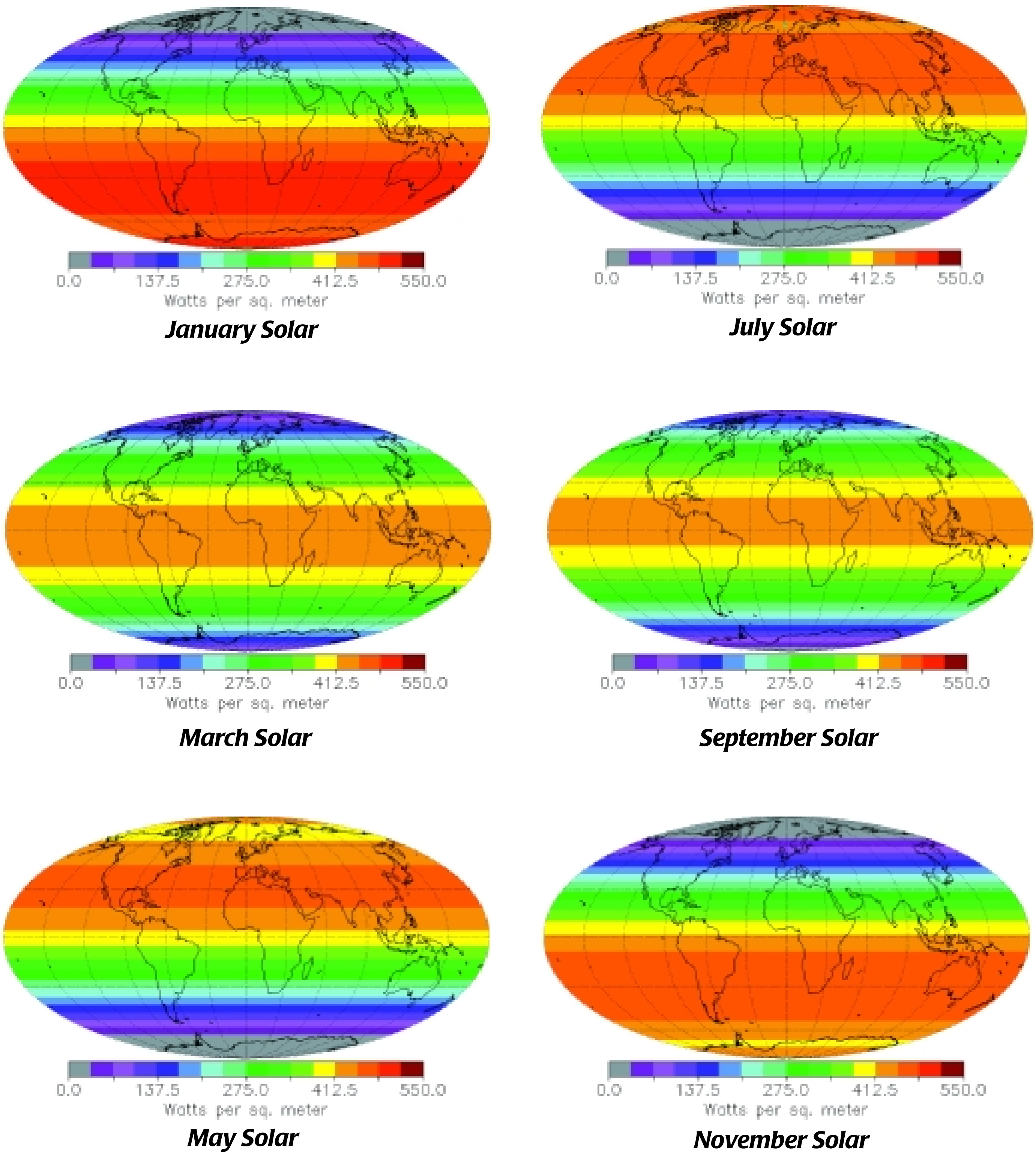


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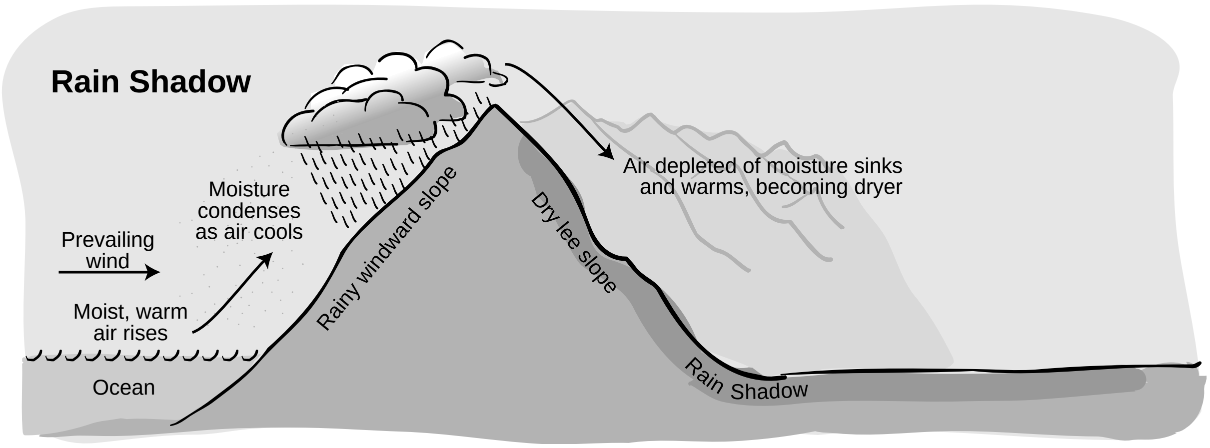
Figure EA-I-10: Mountain producing a rain shadow effect

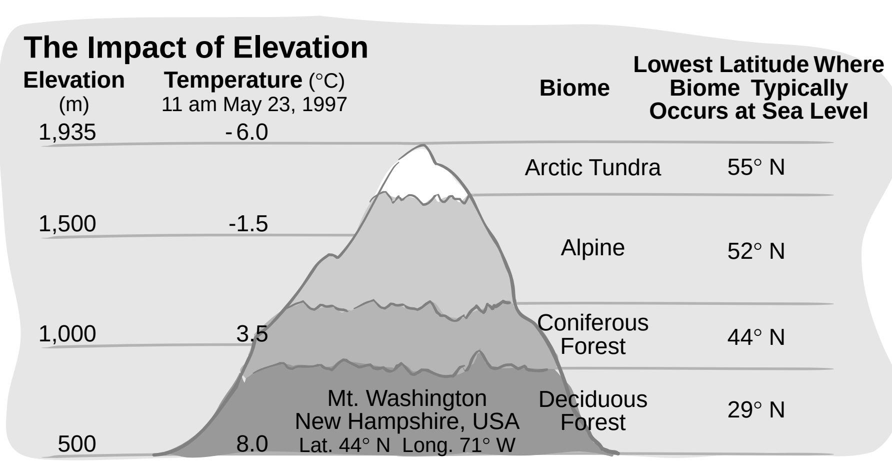


Geographical Features

Geographical features have profound impacts on nearby regions. For example, mountain chains can cause moist air to rise and precipitate out almost all of its moisture. When dry air descends behind the mountain chain, it lacks enough moisture to provide much precipitation. The mountains create a rain shadow. See Figure EA-I-10. Many deserts are found in such rain shadows. In addition to arid land, typical desert regions lack the atmospheric moisture that acts as insulation between the Earth's surface and space (water is the major greenhouse gas on Earth). Consequently, desert areas easily radiate their heat energy out to space, and day and night temperature differences are considerable.

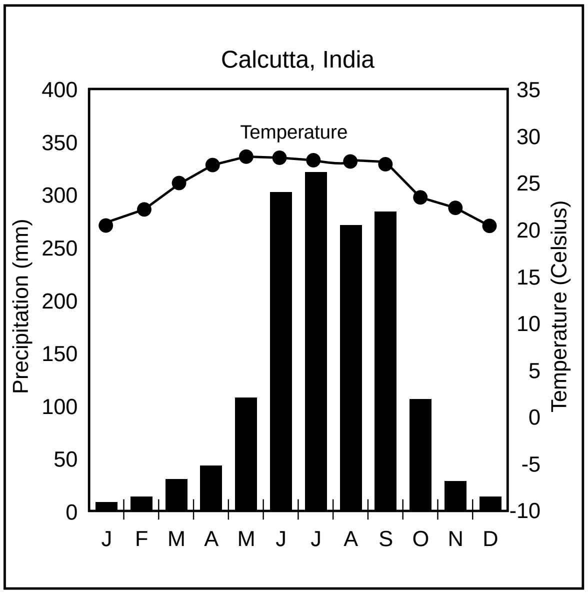
Elevation in particular can influence seasonal patterns. Changes in elevation can affect the environment as much as changes in latitude. Average air temperature falls approximately 1° C for every 150 meter increase in elevation, and, in terms of growing season, every 300 m increase in elevation is roughly equivalent to moving poleward by 400-500 km (roughly four to five degrees of latitude). Mountain tops can be thought of as climatic islands where, in the Northern Hemisphere, northern species extend their ranges southward on mountains where conditions resemble those of more northern latitudes. Plants growing on the top of New Hampshire's Mt. Washington (1,935 m) would feel right at home growing at sea level in the Arctic tundra, 2,400 km to the north in Canada. See Figure EA-I-11.

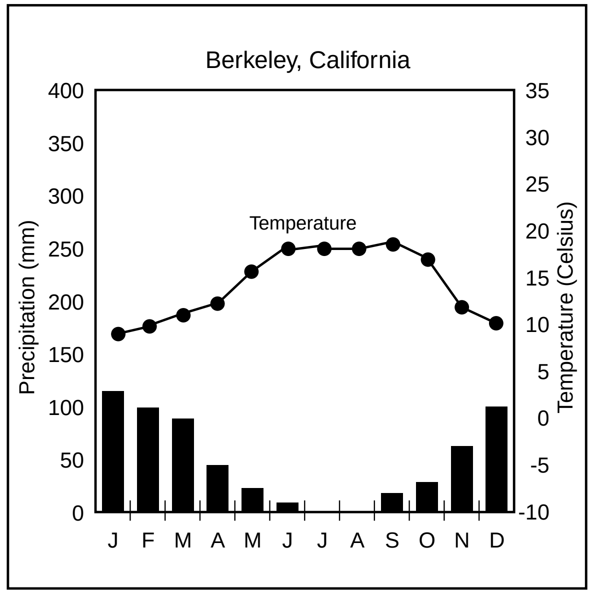
Figure EA-I-11: Impact of elevation on climate zone



Students can study each of these effects by looking at GLOBE school data. A climatogram shows the monthly mean temperature and monthly total water equivalent of the precipitation for the whole year. See Figure EA-I-12. Comparing these diagrams for schools in different areas makes these trends clear.

Figure EA-I-12: Climatograms for Calcutta, India and Berkeley, California





The Earth System through the Seasonal Cycle

In GLOBE, the seasonal cycle plays a role in the timing of some measurements. Examining the GLOBE data through the seasonal cycle can give you some understanding of how Earth works as a system. We can see this by examining some examples of how the seasonal cycle affects different components of the Earth system. The examples here may provide some background material to better understand and interpret GLOBE data. These examples indicate our current understanding and are based on previous studies. Many of the GLOBE data will reveal some of these seasonal patterns. As well, GLOBE data will expand and refine our understanding of seasonal patterns by examining many sites over a long period of time.

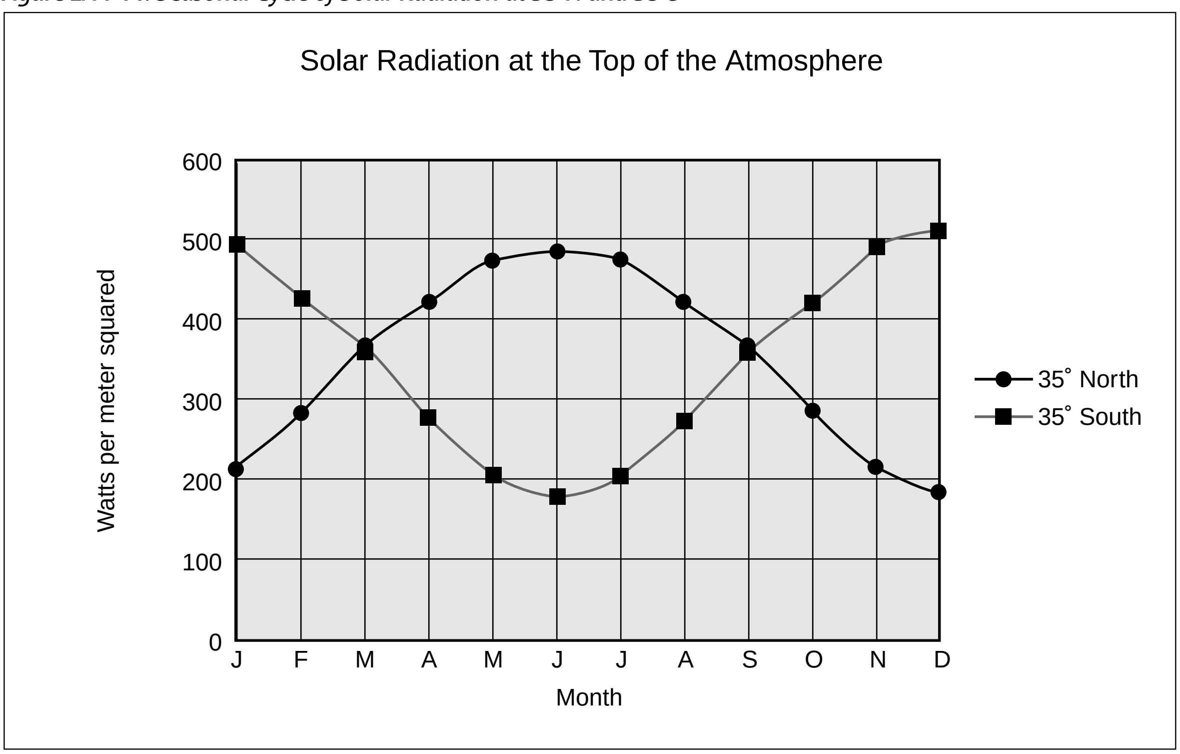
The Atmosphere through the Seasonal Cycle

Temperature

The seasonal change with which people in mid and high latitudes are most familiar is the change in air temperature and number of daylight hours. The air in the lowest layer of the atmosphere is warmed through its contact with Earth's surface. During the summer (July in the northern hemisphere and January in the southern hemisphere), when the elevation of the sun is high, the more concentrated input of energy from the sun and the increase in daylight hours warm the surface which in turn warms the air. During the winter (January in the northern hemisphere and July in the southern hemisphere), when the amount of solar radiation is spread over more surface area because the elevation of the sun is low and there are fewer daylight hours, the sun warms the surface less resulting in less heating of the air. Compare the distribution of solar radiation in January and July (Figure EA-I-7) with the temperature distribution in January and July (Figure EA-I-13) respectively.

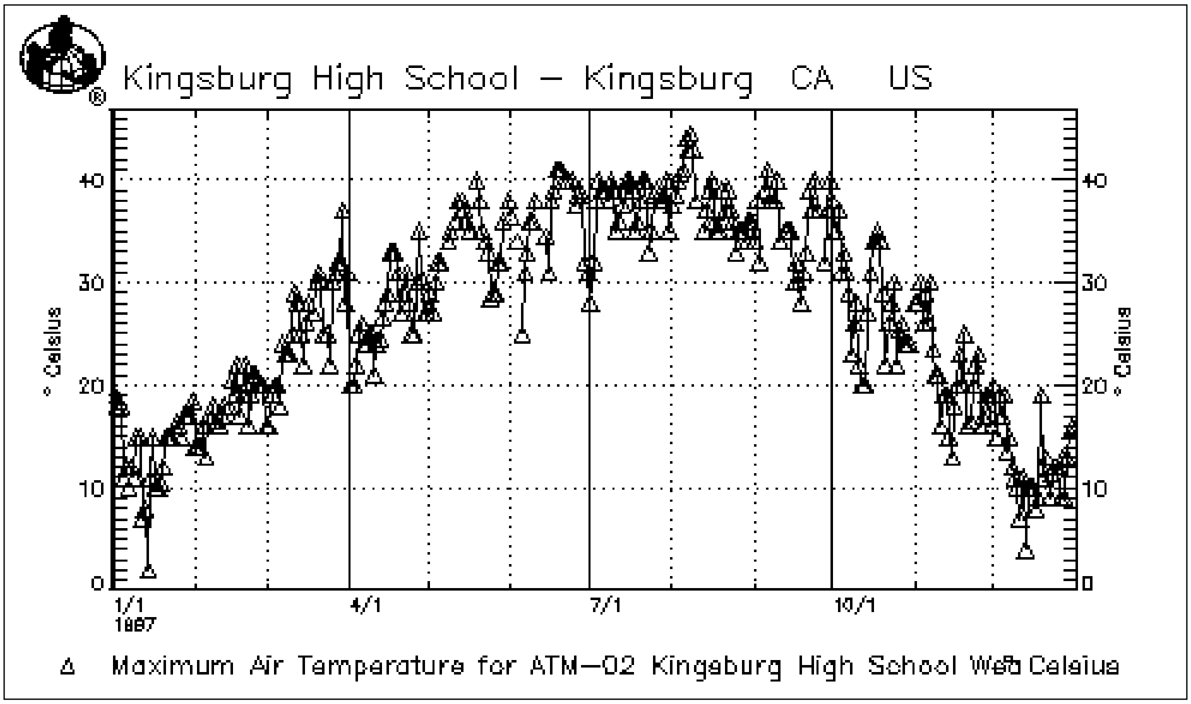
It takes a while for Earth's surface to warm and for the atmosphere to fully respond to these changes in surface warmth. The time when the solar radiation is the strongest outside the tropics is in June in the northern hemisphere and December in the southern hemisphere. See Figure EA-I-14. This is when the solstices occur.

Figure EA-I-14: Seasonal Cycle of Solar Radiation at 35°N and 35°S



However, generally temperatures are warmest about two months later, in August in the northern hemisphere and February in the southern hemisphere. See Figure EA-I-15. This is due to the amount of time required to heat the upper layer of the oceans and the lower layer of the atmosphere.

Figure EA-I-15: Seasonal cycle of maximum surface air temperature at Kingsburg High School in the United States (located at about 35°N) and Shepparton High School in Australia (located at about 35°S)



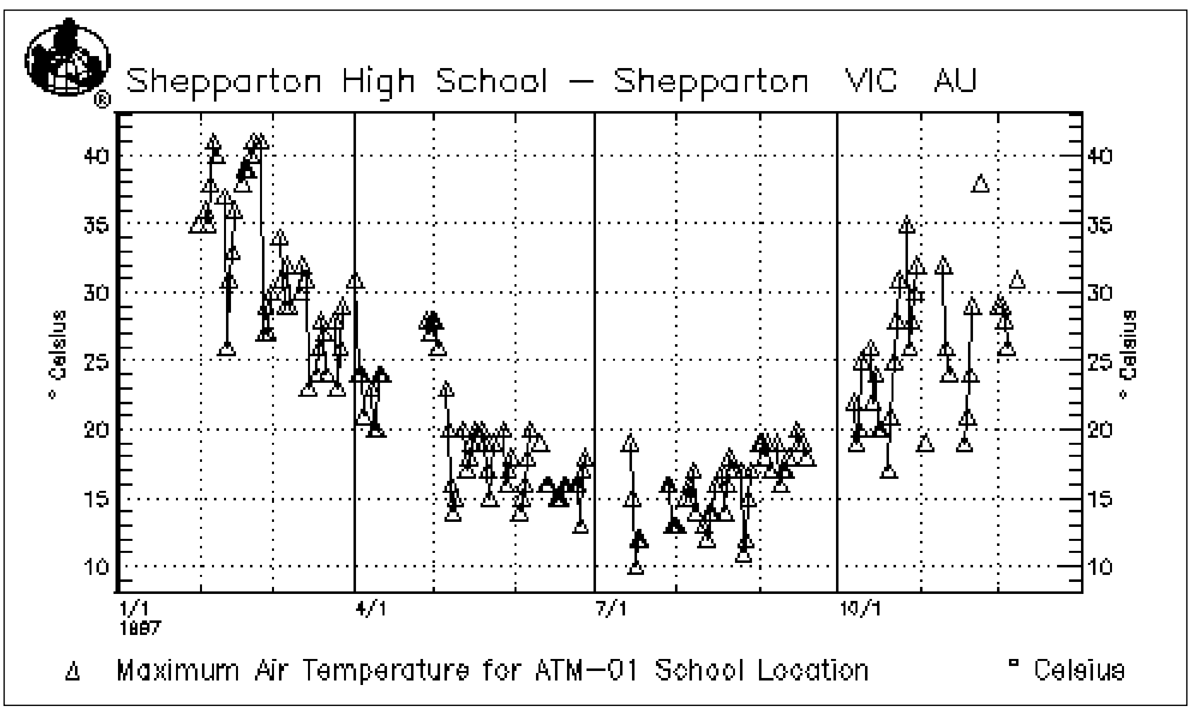
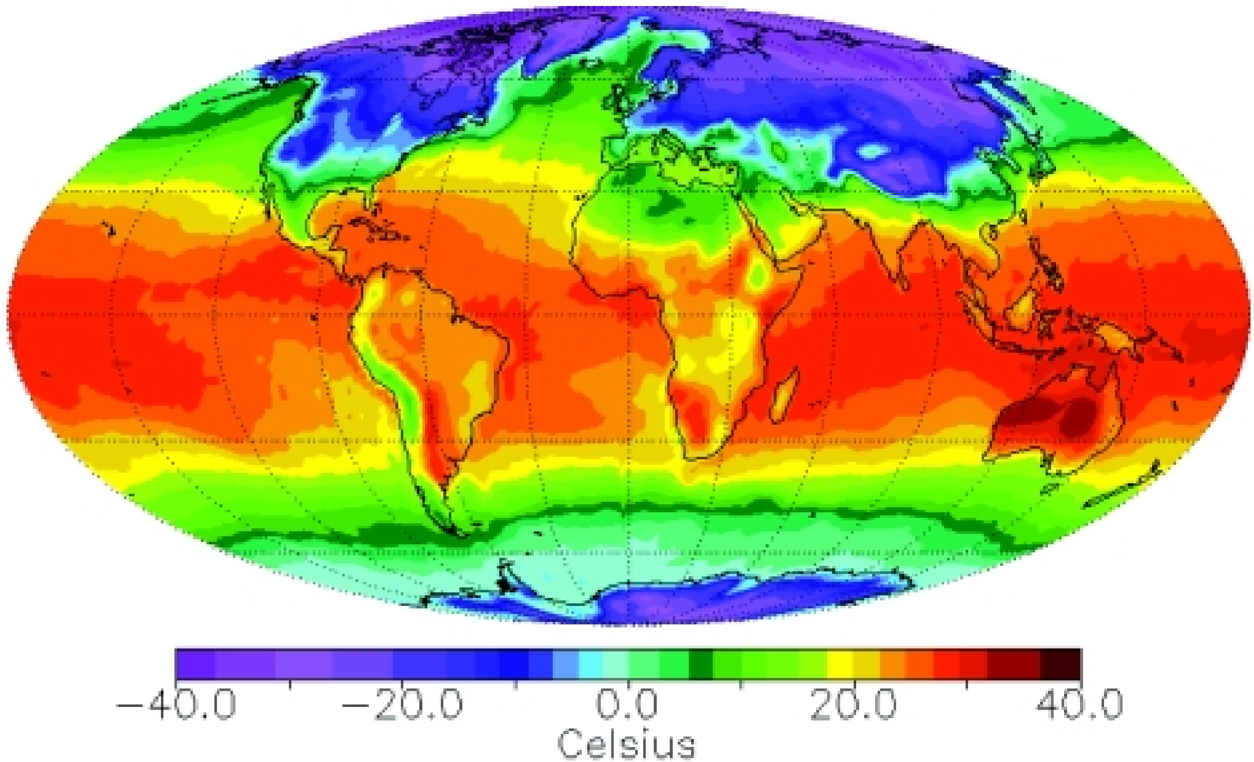
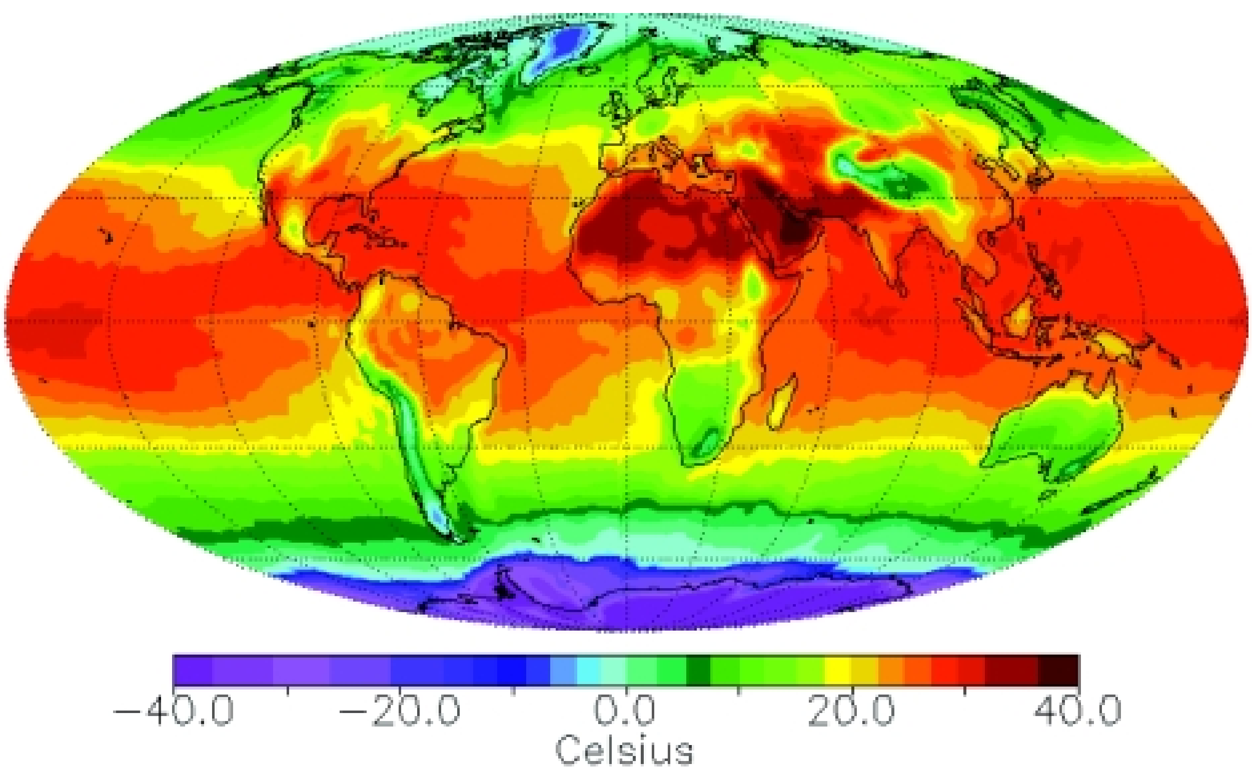


Figure EA-I-13: Global Surface Air Temperature in January and July,1988.



January Air Temperature



July Air Temperature

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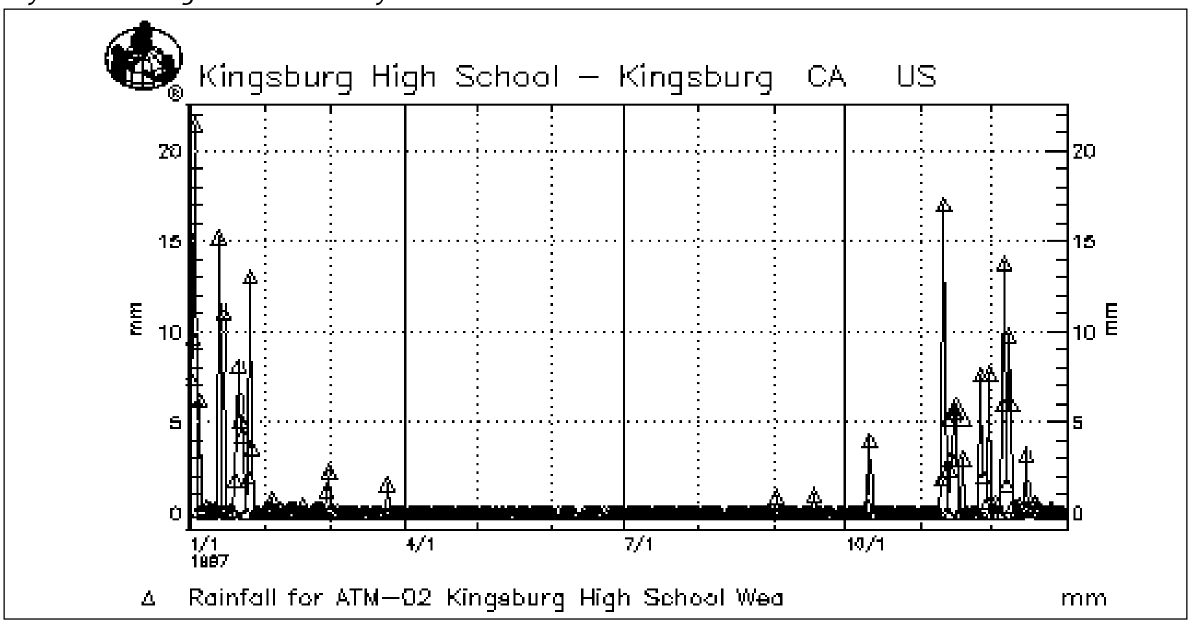
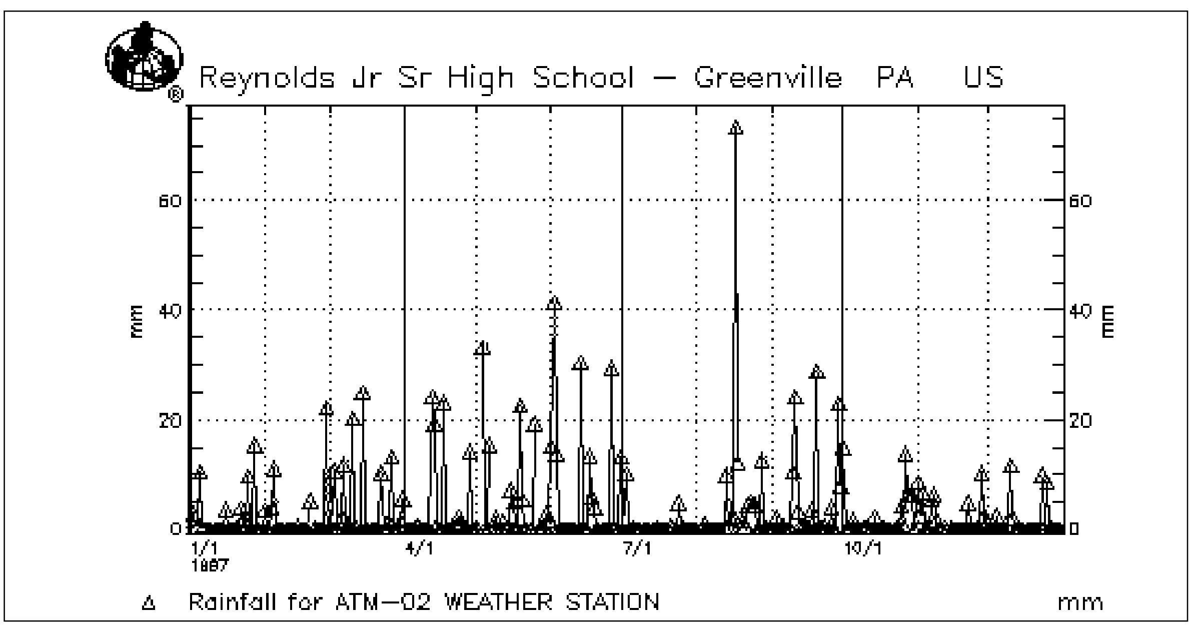
Precipitation

At low latitudes, seasonal temperature changes are not as dramatic as in middle and high latitudes, but there is usually a definite seasonal change in precipitation patterns. Equatorial regions often experience "wet" and "dry" seasons, but the time of year at which these occur is dependent on many factors such as regional topography and proximity to large bodies of water.

Other localities show seasonal patterns in precipitation as well. See Figure EA-I-16. Some regions receive no precipitation for months at a time. In other locations precipitation is evenly distributed throughout the year. Some places have one rainy season and one dry season, while others have two of each during the year. The timing of rains within the year has a major effect on agriculture. Mediterranean climates are characterized by winter rains while some other regions are known for summer rains.

Figure EA-I-16: Seasonal cycle of precipitation through the year at Kingburg High School in California USA and Reynolds Jr. Sr. High School in Pennsylvania USA





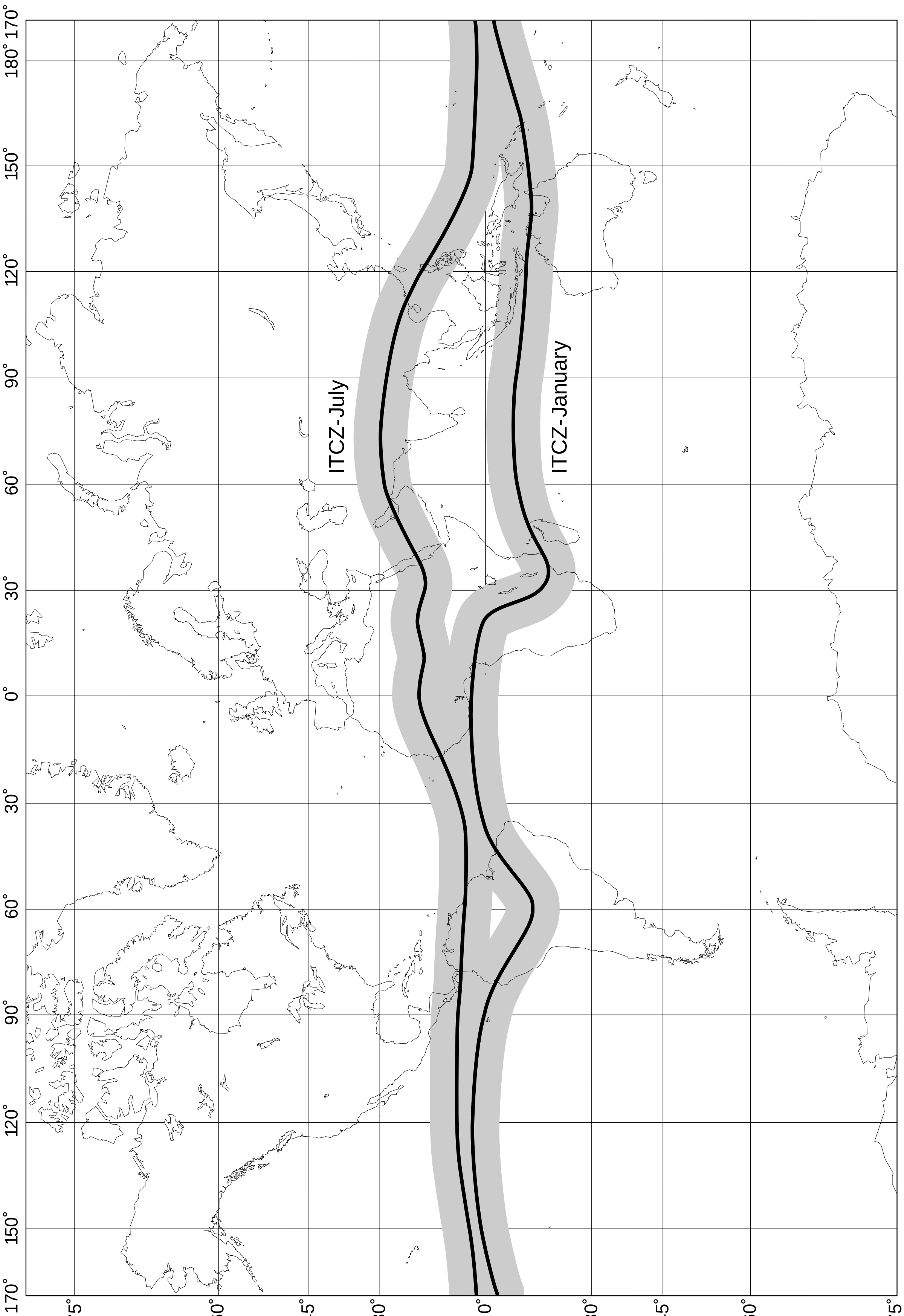


Figure EA-I-17: Average positions of the Intertropical Convergence Zone (ITCZ) in January and July